SPATIOTEMPORAL ANALYSIS OF LOBSTER TRAP CATCHES: IMPACTS OF TRAP FISHING ON COMMUNITY STRUCTURE

BY

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ABSTRACT

Commercial and research lobster trapping, targeting two species of lobster (*Panulirus marginatus* and *Scyllarides squammosus*), began in the Northwestern Hawaiian Islands in the mid 1970s. Commercial fishing effort peaked in 1986 at 1.3 million trap hauls. A corresponding site-specific, depth-stratified research-monitoring program began in 1986 with two sites, Necker Island and Maro Reef, visited annually. Two types of traps were used in the commercial and research fisheries, initially a 2x4-inch-mesh wire trap and later a 1x2-inch-mesh plastic trap. Research trapping was carried out in two depth strata: 18-37 m (shallow) and 38-91 m (deep). Both trap types are highly selective with target species comprising 90% and 73% of the research catch for wire and plastic traps, respectively. Changes in diversity and species abundance of the research trap catches from 1976-2003 are evaluated and discussed in terms of potential impacts due to fishing activity. The Simpson diversity index measured for the community, using plastic trap catch data, showed a significant increase over time for both depth strata at Necker Island, but a significant decline over time for the shallower depth stratum at Maro Reef. Significant increases in species richness for all sites as measured by Margalef's diversity index were strongly related to increases in trapping effort. Simpson's measure of evenness declined significantly over time for both depth strata at Maro Reef. Declines in abundance of both target species attributed to direct removal (harvest) occurred at Necker Island and for spiny lobster at Maro Reef. Declines in abundance for nontarget species were not observed. Increases in species abundance possibly attributed to competitive replacement were observed for slipper lobster at Maro Reef and for nontarget crab species at both study locations. Recent increases in whitetip reef shark abundance were observed for both Necker Island and Maro Reef, but they could not be explained in terms of fishery impacts.

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INTRODUCTION

Impacts of Fishing on the Ecosystem

High biodiversity is thought to provide stability to an ecosystem exposed to stress including anthropogenic disturbances such as pollution and fishing pressure (Jennings and Kaiser, 1998; McCann, 2000; Magurran, 2004; Kiessling, 2005), and the protection of ecosystems and their biodiversity is a goal of many resource management and conservation organizations. All fishing activities impact the ecosystem in some manner. The nature and extent of the impact varies with the fishery, gear used, and effort expended. Due to their extractive nature, fisheries, at the very least, directly reduce the available biomass of target species. Active gears such as trawls and dredges generally have larger impacts to the ecosystem than do passive gears such as traps or hooks (Alverson et al., 1994; Jennings and Kaiser, 1998). Trawls typically have low selectivity for target species with the discarded bycatch comprising as much as 90% of the total catch (Alverson et al., 1994). Active gear can also drastically alter the structure of the habitat, which can lead to changes in biodiversity, species composition, and productivity (Jennings and Kaiser, 1998). Passive gears, by contrast, generally have lower rates of bycatch and are less likely to directly alter the substratum (Alverson et al., 1994; Jennings and Kaiser, 1998). Not all fishing impacts are direct. With the complex interactions within any food web, direct alterations in abundance of any one species may indirectly cause changes in abundance of another dependent species by prey removal, prey release, competitive replacement, or scavenger enhancement.

Diversity measures are comprised of two components, richness and evenness, and various indices emphasize one or the other component differently. Fishing activities can impact either component. In some cases the impacts of fishing activities are restricted to changes in target species size and abundance, either with no observable change in community diversity or species richness (Watson et al., 1996), or with no change in richness but changes, including increases, in diversity due largely to changes in evenness (ICES, 1996; Rice, 2000; Bianchi et al., 2000). In other cases fishing activities have led to declines in richness and diversity through extirpation of target species (Randall and Heemstra, 1991; Jennings et al., 1995; Jennings and Polunin, 1997; Jennings and Kaiser, 1998; Hall, 1999; Gislason et al., 2000).

Northwestern Hawaiian Island Lobster Fishery

The Northwestern Hawaiian Islands (NWHI) is a series of islands, islets, banks, and reefs extending 1,500 nautical miles from Nihoa Island to Kure Atoll. Commercial and research lobster trapping in this region commenced concurrently in the mid-1970s. During the 1980s, the commercial trap fishery was one of Hawaii's most valuable demersal fisheries, valued at approximately $6 million per year (Polovina, 1993). This fishery is a multispecies fishery and primarily targets Hawaiian spiny lobster (*Panulirus marginatus*) and common slipper lobster (*Scyllarides squammosus*). Commercial catch peaked in 1985, and effort peaked in 1986 (Fig. 1); however, the commercial fishery was closed in 2000 due to an increasing lack of confidence in the population models used for management decisions. Research to advance the existing population models is presently underway (DiNardo and Wetherall, 1999).

The nature of the commercial fishery changed over time. When the fishery started in the mid-1970s, one to two vessels targeted Hawaiian spiny lobster in the NWHI each year bringing them back to port alive for the live-lobster market. Trips lasted about 10 days and coupled bottomfishing with lobster trapping with a total of less than 20 trips per year combined. Trapping effort was relatively low, circa 50-100 trap hauls per vessel-day totaling less than 20,000 hauls per year. The standard trap for the fishery was the two-chambered California lobster trap. This was a wire trap with a 2x4-inch mesh. In 1981, vessels began conducting trips dedicated solely to lobster trapping and processed the catch at sea, landing only frozen tails for an export market. The fleet size increased in the early 1980s to as many as 15 vessels fishing in a single year. Trapping effort on these trips increased markedly with trips frequently lasting 40-60 days and approximately 1,000 traps hauled per vessel-day. By the mid-1980s, the gear of choice changed from the wire California trap to a stackable molded plastic trap with a 1x2-inch mesh. This gear change allowed vessels to carry and fish more traps and also resulted in much higher slipper lobster catch rates.

Research trapping by NMFS used similar gear and techniques. Efforts in the late 1970s and early 1980s were largely exploratory in nature, spread thinly throughout the Archipelago. In 1986, a monitoring program was initiated whereby set sites around Necker Island and Maro Reef were visited annually using standardized gear and trapping techniques.

In this study, we analyzed the time series of NWHI lobster trap catches obtained on research cruises. Changes in diversity and species abundance were evaluated and discussed with particular emphasis on changes that can be associated with fishing activities.

METHODS

Field Operations

The National Oceanic and Atmospheric Administration (NOAA) Fisheries Honolulu Laboratory conducted fishery-independent lobster trapping operations in the NWHI since 1976. As in the commercial fishery, two types of traps were used during this time. Two-chambered California lobster traps with a 2x4-inch mesh were used from 1976 through 1991, and molded plastic traps with a 1x2-inch mesh were used from 1986 though the present. Plastic trap escape vents, required to be opened for the commercial fishery, remained closed on the research cruises allowing for greater catchability of small organisms including small individuals of the target species. During research operations, baited traps were set in the afternoon, soaked over night, and then hauled the next day. All organisms captured were identified to the lowest taxonomic level possible, generally the species level, with total counts of each taxon recorded for each trap. In 1986, the Honolulu Laboratory initiated a fixed-site, depth-stratified survey program. Selected sites were sampled annually during early summer at two banks in the NWHI, Necker Island and Maro Reef, with the exception of 1989, when no survey was conducted, and 2003, when only Maro Reef sites were visited. Two depth strata were targeted. Ten strings of 8 traps were set in 18-37 m at each survey site and two to four strings of 20 traps were set in 38-91 m at sites where these depths occurred. At sites where the deeper water was not present, all trap strings were set within the shallower range. From 1986 to 1991, wire traps were used for the strings of 8 traps, and plastic traps were used for the strings of 20 traps. Starting in 1992, plastic traps were used for all sets.

Data Analysis

Raw data from the fishery-independent trap surveys conducted from 1976 to 2003 were summarized by species, year, bank, site, depth, and gear type. Some taxa (e.g., hermit crabs, moray eels, and sharks) were poorly identified on a few earlier research cruises (e.g., to the genus or family level only), particularly on the 1991 cruise. For the purpose of analysis in this study, individuals of those poorly identified taxa within any site strata (bank/site/depth) were allotted amongst the probable species based on the relative abundances of those component species within that strata recorded for other years. Data for specific trapping sites at each bank were pooled into four bank/depth bins for diversity and abundance analysis. These bins are: Necker Island 18-37 m, Necker Island 38-91 m, Maro Reef 18-37 m, and Maro Reef 38-91 m. Data were excluded for years when less than 50 traps were fished within a particular bin.

Simpson's diversity (1/D), Simpson's measure of evenness ($E_{1/D}$), and Margalef's diversity (a measure of richness) indices were calculated as follows for the four sampling bins.

Simpson's Diversity Index (1/D): $1/D = 1/\Sigma((n(n-1))/(N(N-1)))$
Simpson's Measure of Evenness: $E_{1/D} = (1/D)/S$
Margalef's Diversity Index: $D_{Mg} = (S-1)/\ln(N)$
where n = number of individuals of a particular species
N = total number of individuals of all species in the sample

and S = total number of species in the sample

Catch-per-unit-effort (CPUE), in terms of number per trap-haul, was calculated for species groups based on those species that comprised at least 1.0% of the catch in plastic lobster traps (spiny lobster, slipper lobster, hermit crabs, calappid crabs, portunid crabs, moray eels, and *Heniochus diphreutes*). Two additional groups, octopus and the whitetip reef shark, *Triaenodon obesus*, were added to the analysis for reasons explained in the discussion section. In order to compare patterns of species with very different catch rates, CPUE values for each species were indexed by their median value. Indexing results in a 1.0 value representing the "normal" catch rate, 0.5 being one half normal, 6.0 being six times normal, etc. The indexed CPUE values were then graphed together to compare abundance patterns. Linear regressions were applied to each series of diversity and indexed CPUE values using Microsoft Excel data analysis tools. Significant regressions at the 95% confidence level, positive or negative, were considered as evidence of possible fishing impact.

RESULTS AND DISCUSSION

Selectivity

Both wire and plastic lobster traps are highly selective gears for lobsters. Wire traps set between 1976 and 1991 on research cruises caught a total of 82 species (Table 1). Of these species, the two target species of lobster accounted for 90.5% of the catch by number. Plastic trap catches from 1986 to 2003 contained 258 species (Table 2) of which 73.1% were the two target species. For both gears the two target species were most abundant in the catches. Also, two species of *Dardanus* hermit crabs were next in abundance for both gears, with the moray eel (*Gymnothorax steindachneri*) within the top ten in both cases. Ridgeback slipper lobster (*Scyllarides haanii*), a large reef fish (*Melichthys niger*), and adults of three bottomfish species (*Pristipomoides filamentosus*, *Epinephelus quernus*, and *Pseudocaranx cheilio*), rounded out the top ten for the wire traps, whereas three sand-dwelling crabs (*Calappa calappa*, *Charybdis hawaiiensis*, and *Ranina ranina*), and two small reef-fish species (*Heniochus diphreutes* and *Pervagor spilosoma*) did so for the plastic traps. It is interesting to note that, with the exception of juveniles of *Epinephelus quernus*, bottomfish species were not caught with the plastic traps. This may be a result of these species avoiding the plastic traps, similar to the behavior of avoiding structure, including plastic traps, observed by Moffitt and Parrish (1996) for juvenile *Pristipomoides filamentosus*.

The smaller mesh size of the plastic traps was likely responsible for the greater number of species captured, most of which were small species. These traps were nearly equal to wire traps in their ability to catch spiny lobster, but were much better at catching slipper lobster (Table 3). Although the number of species caught in the plastic traps was much greater than in the wire traps, this gear was still highly selective. The top nine species comprised 90% of the catch by number (Table 2). Of the remaining species, 181 of them (70% of the 258 species total) were represented in the catch by 18 or less individuals, which means they averaged only one individual caught per year of research trapping compared to an average catch of 4,114 targeted lobsters per year.

Diversity

Because the traps used in the NWHI lobster fishery were highly selective for target species, they did not provide a very accurate measurement of the diversity of the reef community on the lobster fishing grounds. However, changes in diversity indices measured by these traps over time could indicate whether fishing activity may have altered the diversity of the benthic community. Because the wire and plastic traps had different catchability characteristics for most species, the results could not be pooled across trap types, therefore only plastic trap results are included below. Unfortunately, diversity indices are strongly influenced by sample size (Kaiser, 2003; Magurran, 2004), and the sampling effort in this study fluctuated (generally increased) over time. The indices used in this study were selected for their resistance to sample size influences.

Results of the linear regressions for diversity indices and species abundances over time are listed in Table 3. The Simpson diversity indices obtained for three of the four bank-depth bins displayed significant trends (Fig. 2). At Necker Island the observed diversity increased over time for both depth bins, whereas at Maro Reef a significant decline was observed for the shallower depth bin. Richness (Margalef's diversity index) and evenness components were evaluated separately and can help explain the observed changes in the diversity indices. Margalef's index was selected as the measure of richness for this paper because of its resistance to sample size bias (Margurran, 2004). Despite this resistance, evaluation of species richness over time for the four bins showed a significant increase in all cases, largely mirroring changes in trapping effort and probably not reflecting actual increases in species richness in the benthic community. Regressions of effort and Margalef's indices were significantly positive for all bins (Table 4). The relationship between richness and trapping effort over time for Necker Island 18-37 m is shown in Figure 3. Significant decreases in species evenness were observed for both depths at Maro Reef and are likely due to the large increase in slipper lobster abundance described below. Changes in evenness for Necker Island, on the other hand, were not significant. No significant increase in the evenness component with the fishing down of abundant target species as reported by ICES (1996) and Rice (2000) was observed in our study. In light of the changes in richness and evenness components of the diversity indices, it is likely that increases measured for Necker can be attributed to increases in the richness component as a result of increased sampling effort. For Maro Reef, decreases in the evenness component may have counteracted the observed increases in the species richness indices leading to a significant decline in diversity for the 18-37-m depth bin and no significant change in the 38-91-m bin.

Relative Abundance

Only lobsters showed a significant decline in abundance (Table 4). Spiny lobster CPUE values show significant declines as expected for three of the four sampling bins. The exception was the deeper (38-91 m) bin at Maro Reef, where spiny lobsters were never particularly abundant, and the observed declines in this bin were not significant. Changes in slipper lobster abundance showed a different pattern. Necker 18-37 m slipper lobster CPUE significantly declined in a similar manner to that of spiny lobster, whereas declines in the deeper bin were not significant. Slipper lobster abundance at Maro Reef, however, showed increases, significant at the shallower depths but not the deeper (Fig. 4). This increase in abundance is likely a case of competitive replacement in response to the drastic drop in spiny lobster abundance at the shallower depths at Maro Reef; slipper lobsters were able to outpace the decline in abundance expected from commercial harvest.

All other species groups examined showed either a positive trend or no significant trend in abundance over time. The nontargeted crustaceans groups, hermit crabs, calappid crabs, and portunid crabs, all showed a positive trend in CPUE in the shallow bin at Necker. These increases may be due to competitive replacement in response to declining lobster abundance. Hermit crabs showed no significant trend in the other sampling bins, calappid abundance increased in the 38-91-m bin at Necker, and portunids increased in both depth bins at Maro. The only reef-fish species in the top 90% of the catch, *Heniochus diphreutes*, showed no significant linear trends in abundance for any sampling bin. In spite of this, their pattern of abundance is interesting (Fig. 5). These fish were caught as recently settled juveniles, and their abundance in the catch for any year may reflect year-class recruitment strength. As can be seen, abundance fluctuated markedly between years, most notably at Maro. Changes in abundance of the whitetip reef shark are presented in Figure 6. It was included in this paper due to its interesting pattern. As can be seen, abundance was low for most of the study period, but has increased markedly in the last few years at both Necker Island and Maro Reef. This increase is not likely related to fishing activity (e.g., competitive replacement or scavenger enhancement) and remains unexplained. Finally, octopus abundance was evaluated due to its potential as an important prey item for the endangered Hawaiian monk seal (*Monachus schauinslandi*). As can be seen in Table 3, octopus are a relatively rare item in our trap catches with only 83 individuals captured in the 1986-2003 study period. Furthermore, examination of research CPUE data shows no significant decline or increase in abundance over time.

CONCLUSION

In conclusion, lobster trapping activities have likely contributed to changes in abundance of a few species of the benthic community on the NWHI lobster fishing grounds, but do not appear to have resulted in major changes to the ecosystem. Significant declines in species abundance through direct removal (harvest) appear to be limited to the target species. Competitive replacement may have led to increases in abundance of several nontarget crab species and the targeted slipper lobster at Maro Reef. Direct damage to the benthic habitat by the traps has not been studied, but is not likely to be substantial due to the low relief, hard substrate that characterizes the fishing grounds (Parrish and Boland, 2004). Future researchers may be able to measure and document the resiliency of the lobster populations now that commercial fishing has stopped.

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Table 1. Species caught in wire traps, 1976-1991.

Species	#	%	Cum %	Species	#	%	Cum %
Panulirus marginatus	21749	81.6098	81.6098	*Aluterus scriptus*	7	0.0263	99.6510
Scyllarides squamosus	2368	8.8856	90.4953	*Calappa calappa*	5	0.0188	99.6698
Dardanus gemmatus	1034	3.8799	94.3752	*Gymnothorax albimarginatus*	5	0.0188	99.6886
Dardanus brachyops	374	1.4034	95.7786	*Chaetodon miliaris*	5	0.0188	99.7073
Gymnothorax steindachneri	322	1.2083	96.9869	*Panulirus penicillatus*	4	0.0150	99.7223
Pristipomoides filamentosus	80	0.3002	97.2871	*Carpilius maculatus*	4	0.0150	99.7373
Epinephelus quernus	70	0.2627	97.5497	*Echinothrix calamaris*	4	0.0150	99.7523
Scyllarides haanii	68	0.2552	97.8049	*Gymnothorax berndti*	3	0.0113	99.7636
Pseudocaranx dentex	56	0.2101	98.0150	*Conger cinereus marginatus*	3	0.0113	99.7749
Melichthys niger	52	0.1951	98.2101	*Parupeneus porphyreus*	3	0.0113	99.7861
Bodianus bilunulatus	45	0.1689	98.3790	*Parupeneus insularis*	3	0.0113	99.7974
Carcharhinus amblyrhynchos	37	0.1388	98.5178	*Kyphosus bigibbus*	3	0.0113	99.8086
Astopyga radiate	31	0.1163	98.6341	*Heniochus diphreutes*	3	0.0113	99.8199
Carpilius convexus	30	0.1126	98.7467	*Luidia magnifica*	2	0.0075	99.8274
Gymnothorax undulatus	29	0.1088	98.8555	*Eucidaris metularia*	2	0.0075	99.8349
Melichthys vidua	25	0.0938	98.9493	*Sargocentron xantherythrum*	2	0.0075	99.8424
Ranina ranina	24	0.0901	99.0394	*Caranx ignobilis*	2	0.0075	99.8499
Dardanus "purple leg"	22	0.0826	99.1220	*Parupeneus chrysonemus*	2	0.0075	99.8574
Dromidiopsis dormia	22	0.0826	99.2045	*Acanthurus olivaceus*	2	0.0075	99.8649
Dardanus sanguinocarpus	19	0.0713	99.2758	*Sufflamen fraenatus*	2	0.0075	99.8724
Parribacus antarcticus	13	0.0488	99.3246	*Pervagor spilosoma*	2	0.0075	99.8799
Dardanus megistros	13	0.0488	99.3734	*Pherecardia striata*	1	0.0038	99.8837
Seriola dumerili	13	0.0488	99.4221	*Plesionika sp.*	1	0.0038	99.8874
Triaenodon obesus	11	0.0413	99.4634	*Parthenope contrarius*	1	0.0038	99.8912
Octopus cyanea	10	0.0375	99.5009	*Lissocarcinus laevis*	1	0.0038	99.8949
Octopus sp.	9	0.0338	99.5347	*Conus quercinus*	1	0.0038	99.8987
Gymnothorax flavimarginatus	8	0.0300	99.5647	*Conus vexillum*	1	0.0038	99.9024
Sargocentron spiniferum	8	0.0300	99.5947	*Leiaster leachi hawaiiensis*	1	0.0038	99.9062
Bodianus sp	8	0.0300	99.6248	*Linckia guildingi*	1	0.0038	99.9099

Table 1. Species caught in wire traps, 1976-1991(Con'td)

Species	#	%	Cum %	Species	#	%	Cum %
Linckia multifora	1	0.0038	99.9137	*Priacanthus alalaua*	1	0.0038	99.9587
Ophiuroidea	1	0.0038	99.9174	*Carangoides orthogrammus*	1	0.0038	99.9625
Diadema paucispinum	1	0.0038	99.9212	*Parupeneus pleurostigma*	1	0.0038	99.9662
Opheodesoma spectabilis	1	0.0038	99.9250	*Kyphosus vaigiensis*	1	0.0038	99.9700
Bathycongrus sp.	1	0.0038	99.9287	*Chaetodon fremblii*	1	0.0038	99.9737
Conger oligoporus	1	0.0038	99.9325	*Polydactylus sexfilis*	1	0.0038	99.9775
Myrichthys magnificus	1	0.0038	99.9362	*Thalassoma purpureum*	1	0.0038	99.9812
Synodus capricornis	1	0.0038	99.9400	*Thalassoma ballieui*	1	0.0038	99.9850
Physiculus rhodopinnis	1	0.0038	99.9437	*Coris ballieui*	1	0.0038	99.9887
Scorpaenodes corallinus	1	0.0038	99.9475	*Acanthurus blochii*	1	0.0038	99.9925
Segastapistes ballieui	1	0.0038	99.9512	*Thamnaconus garretti*	1	0.0038	99.9962
Segastapistes galactacma	1	0.0038	99.9550	*Sphoeroides pachygaster*	1	0.0038	100.0000

Table 2. Species caught in plastic traps, 1986-2003.

Species	#	%	Cum %
Panulirus marginatus	37277	36.79281	36.79281
Scyllarides squamosus	36783	36.30522	73.09803
Dardanus gemmatus	6297	6.215208	79.3132
Dardanus brachyops	3816	3.766434	83.0797
Calappa calappa	2284	2.254333	85.3340
Charybdis hawaiensis	1801	1.777607	87.1116
Gymnothorax steindachneri	1363	1.345296	88.4569
Heniochus diphreutes	1134	1.11927	89.5762
Ranina ranina	550	0.542856	90.1190
Pervagor spilosoma	468	0.461921	90.5810
Sargocentron xantherythrum	464	0.457973	91.0389
Carpilius convexus	464	0.457973	91.4969
Pseudanthias thompsoni	458	0.452051	91.9490
Scyllarides haanii	458	0.452051	92.4010
Parupeneus pleurostigma	443	0.437246	92.8382
Gymnothorax undulatus	406	0.400726	93.2390
Chaetodon miliaris	350	0.345454	93.5844
Triaenodon obesus	342	0.337558	93.9220
Canthigaster jactator	330	0.325714	94.2477
Aulostomus chinensis	325	0.320779	94.5685
Pherecardia striata	312	0.307947	94.8764
Dromidiopsis dormia	259	0.255636	95.1321
Lutjanus kasmira	247	0.243792	95.3759
Parribacus antarcticus	234	0.230961	95.6068
Calappa pokipoki	220	0.217142	95.8240
Dardanus "purple leg"	218	0.215168	96.0391
Carpilius maculates	212	0.209246	96.2484
Lupocyclus quinquedentatus	202	0.199376	96.4477
Epinephelus quernus	166	0.163844	96.6116

Species	#	%	Cum %
Panulirus penicillatus	160	0.157922	96.7695
Parupeneus multifasciatus	156	0.153974	96.9235
Segastapistes ballieui	152	0.150026	97.0735
Thalamita auauensis	143	0.141143	97.2147
Parthenope contrarius	131	0.129298	97.3440
Astopyga radiata	123	0.121402	97.4654
Chaetodon fremblii	96	0.094753	97.5601
Myrichthys magnificus	91	0.089818	97.6499
Gymnothorax albimarginatus	86	0.084883	97.7348
Dendrochirus barberi	84	0.082909	97.8177
Cirrhitops fasciatus	79	0.077974	97.8957
Parupeneus insularis	79	0.077974	97.9737
Homola dickinsoni	78	0.076987	98.0507
Carcharhinus amblyrhynchos	65	0.064156	98.1148
Conger cinereus marginatus	63	0.062182	98.1770
Dardanus sanguinocarpus	63	0.062182	98.2392
Luidia magnifica	61	0.060208	98.2994
Charybdis paucidentata	59	0.058234	98.3576
Nassarius hirtus	57	0.05626	98.4139
Nassarius papillosus	56	0.055273	98.4691
Octopus sp.	55	0.054286	98.5234
Torquigener sp.	52	0.051325	98.5748
Gymnothorax flavimarginatus	48	0.047377	98.6221
Dardanus megistros	48	0.047377	98.6695
Apogon maculiferus	45	0.044415	98.7139
Gymnothorax berndti	45	0.044415	98.7583
Dairoides kusei	36	0.035532	98.7939

Table 2. Species caught in plastic traps, 1986-2003 (Con'td)

Species	#	%	Cum %
Luzonichthys earlei	31	0.030597	98.8245
Pseudanthias bicolor	31	0.030597	98.8551
Enoplometopus occidentalis	31	0.030597	98.8857
Chromis ovalis	30	0.02961	98.9153
Gymnothorax melatremus	30	0.02961	98.9449
Fusinus sandvichensis	30	0.02961	98.9745
Plesionika sp.	30	0.02961	99.0041
Octopus cyanea	27	0.026649	99.0308
Priacanthus alalaua	26	0.025662	99.0564
Nudibranchia (includes at least 1 *Halgerda terramfuensis*)	26	0.025662	99.0821
Canthigaster rivulata	24	0.023688	99.1058
Thalamita picta	24	0.023688	99.1295
Bothus thompsoni	22	0.021714	99.1512
Vexillum pacificum	20	0.01974	99.1709
Cycloes granulose	20	0.01974	99.1907
Acanthurus olivaceus	19	0.018753	99.2094
Thalassoma ballieui	19	0.018753	99.2282
Gymnothorax meleagris	19	0.018753	99.2469
Echinothrix calamaris	19	0.018753	99.2657
Linckia multifora	19	0.018753	99.2844
Thalamita admete	19	0.018753	99.3032
Linckia guildingi	17	0.016779	99.3199
Canthigaster coronata	16	0.015792	99.3357
Cantherhines verecundus	16	0.015792	99.3515
Nassarius splendidulus	16	0.015792	99.3673
Scyllarus aurora	16	0.015792	99.3831
Gymnothorax eurostus	15	0.014805	99.3979
Coris ballieui	13	0.012831	99.4108
Myripristis chryseres	13	0.012831	99.4236

Species	#	%	Cum %
Ophiuroidea	13	0.012831	99.4364
Progeryon mus	13	0.012831	99.4492
Fusinus michaelrogersi	12	0.011844	99.4611
Nassarius gaudiosus	12	0.011844	99.4729
Lissocarcinus laevis	12	0.011844	99.4848
Plectroglyphidodon johnstonianus	11	0.010857	99.4956
Parupeneus chrysonemus	11	0.010857	99.5065
Synodus ulae	11	0.010857	99.5174
Mithrodia fisheri	11	0.010857	99.5282
Trizopagurus strigatus	11	0.010857	99.5391
Turbo sandwicensis	10	0.00987	99.5489
Justitia longimana	10	0.00987	99.5588
Heterocarpus ensifer	10	0.00987	99.5687
Sargocentron diadema	9	0.008883	99.5776
Eucidaris metularia	9	0.008883	99.5864
Odontodactylus hawaiiensis	9	0.008883	99.5953
Cirrhitus pinnulatus	8	0.007896	99.6032
Dascyllus albisella	8	0.007896	99.6111
Chaetodon kleinii	8	0.007896	99.6190
Conger oligoporus	8	0.007896	99.6269
Bursa luteostoma	8	0.007896	99.6348
Thalamita wakensis	8	0.007896	99.6427
Lahaina ovata	8	0.007896	99.6506
Aniculus maximus	8	0.007896	99.6585
Calotomus zonarcha	7	0.006909	99.6654
Priacanthus meeki	7	0.006909	99.6723
Gymnothorax nudivomer	7	0.006909	99.6792
Squalus mitsukurii	7	0.006909	99.6861
Huenia pacifica	7	0.006909	99.6930

Table 2. Species caught in plastic traps, 1986-2003 (Con'td)

Species	#	%	Cum %
Portunus sanguinolentis	6	0.005922	99.6990
Melichthys niger	5	0.004935	99.7039
Centropyge potteri	5	0.004935	99.7088
Seriola dumerili	5	0.004935	99.7138
Scorpaenodes littoralis	5	0.004935	99.7187
Myripristis kuntee	5	0.004935	99.7236
Ariosoma marginatum	5	0.004935	99.7286
Pentaceraster cumingi	5	0.004935	99.7335
Chlorodiella laevissima	5	0.004935	99.7384
Paromola alcocki	5	0.004935	99.7434
Calotomus carolinus	4	0.003948	99.7473
Chromis hanui	4	0.003948	99.7513
Chromis vanderbilti	4	0.003948	99.7552
Parupeneus porphyreus	4	0.003948	99.7592
Mulloidichthys vanicolensis	4	0.003948	99.7631
Mulloidichthys flavolineatus	4	0.003948	99.7671
Segastapistes galactacma	4	0.003948	99.7710
Iracundus signifier	4	0.003948	99.7750
Hippocampus sp.	4	0.003948	99.7789
Bathycongrus sp.	4	0.003948	99.7829
Pyrosomata	4	0.003948	99.7868
Leiaster leachi hawaiiensis	4	0.003948	99.7908
Atyidae (includes at least 1 *Haminoea curta)*	4	0.003948	99.7947
Bulla vernicosa	4	0.003948	99.7986
Fusinus midwayensis	4	0.003948	99.8026
Calcinus laurentae	4	0.003948	99.8065
Bothus mancus	3	0.002961	99.8095
Apogon kallopterus	3	0.002961	99.8125
Scorpaenopsis brevifrons	3	0.002961	99.8154

Species	#	%	Cum %
Scorpaenodes corallinus	3	0.002961	99.8184
Rhinopias xenops	3	0.002961	99.8214
Pristilepis oligolepis	3	0.002961	99.8243
Physiculus rhodopinnis	3	0.002961	99.8273
Antennarius commerson	3	0.002961	99.8302
Gymnothorax javanicus	3	0.002961	99.8332
Bohadschia paradoxa	3	0.002961	99.8362
Culcita novaeguineae	3	0.002961	99.8391
Mitrella bella	3	0.002961	99.8421
Pinaxia versicolor	3	0.002961	99.8450
Drupa grossularia	3	0.002961	99.8480
Bursa rhodostoma	3	0.002961	99.8510
Lophozozymus dodone	3	0.002961	99.8539
Thalamita spinifera	3	0.002961	99.8569
Scylla serrata	3	0.002961	99.8598
Portunus pubescens	3	0.002961	99.8628
Daldorfia rathbuni	3	0.002961	99.8658
Hyastenus sp.	3	0.002961	99.8687
Galathea spinosorostris	3	0.002961	99.8717
Fungia scutaria	3	0.002961	99.8746
Canthigaster epilampra	2	0.001974	99.8766
Sufflamen fraenatus	2	0.001974	99.8786
Bothus pantherinus	2	0.001974	99.8806
Thalassoma purpureum	2	0.001974	99.8825
Oxycheilinus bimaculatus	2	0.001974	99.8845
Cheilodactylus vittatus	2	0.001974	99.8865
Paracirrhites arcatus	2	0.001974	99.8885
Chaetodon multicinctus	2	0.001974	99.8904
Sebastapistes coniorta	2	0.001974	99.8924

Table 2. Species caught in plastic traps, 1986-2003 (Con'td)

Species	#	%	Cum %
Scorpaenopsis diabolus	2	0.001974	99.8944
Pterois sphex	2	0.001974	99.8964
Neoniphon sammara	2	0.001974	99.8983
Sargocentron punctatissimum	2	0.001974	99.9003
Sargocentron spiniferum	2	0.001974	99.9023
Antennarius pictus	2	0.001974	99.9043
Synodus falcatus	2	0.001974	99.9062
Synodus amaranthus	2	0.001974	99.9082
Enchelycore pardalis	2	0.001974	99.9102
Opheodesoma spectabilis	2	0.001974	99.9122
Stichopus horrens	2	0.001974	99.9141
Diadema paucispinum	2	0.001974	99.9161
Acanthaster planci	2	0.001974	99.9181
Pleurobranchus sp.	2	0.001974	99.9201
Conus pertusus	2	0.001974	99.9220
Morula granulate	2	0.001974	99.9240
Bursa rosa	2	0.001974	99.9260
Strombus vomer hawaiensis	2	0.001974	99.9279
Lybia edmondsoni	2	0.001974	99.9299
Etisus splendidus	2	0.001974	99.9319
Actaea nodulosa	2	0.001974	99.9339
Carpilodes rubber	2	0.001974	99.9358
Lyreidus tridentatus	2	0.001974	99.9378
Diodon holocanthus	1	0.000987	99.9388
Thamnaconus garretti	1	0.000987	99.9398
Acanthurus nigrofuscus	1	0.000987	99.9408
Acanthurus triostegus sandvicensis	1	0.000987	99.9418
Gobiidae	1	0.000987	99.9428
Exallias brevis	1	0.000987	99.9437
Scarus sp.	1	0.000987	99.9447
Coris venusta	1	0.000987	99.9457
Bodianus sp	1	0.000987	99.9467
Amblycirrhitus bimacula	1	0.000987	99.9477
Apolemichthys arcuatus	1	0.000987	99.9487
Forcipiger flavissimus	1	0.000987	99.9497
Kyphosus vaigiensis	1	0.000987	99.9506
Kyphosus bigibbus	1	0.000987	99.9516
Mulloidichthys pfluegeri	1	0.000987	99.9526
Naucrates doctor	1	0.000987	99.9536
Apogon erythrinus	1	0.000987	99.9546
Dactyloptena orientalis	1	0.000987	99.9556
Caracanthus typicus	1	0.000987	99.9566
Neoniphon aurolineatus	1	0.000987	99.9576
Sargocentron tiere	1	0.000987	99.9585
Brotula multibarbata	1	0.000987	99.9595
Synodus capricornis	1	0.000987	99.9605
Gymnothorax ypsilon	1	0.000987	99.9615
Scuticaria okinawae	1	0.000987	99.9625
Pectinidae	1	0.000987	99.9635
Aplysia sp.	1	0.000987	99.9645
Terebra thaanumi	1	0.000987	99.9655
Terebra chlorata	1	0.000987	99.9664
Terebra gouldi	1	0.000987	99.9674
Conus textile	1	0.000987	99.9684
Conus pulicarius	1	0.000987	99.9694
Conus abbreviatus	1	0.000987	99.9704
Conus striatus	1	0.000987	99.9714
Latirus nodatus	1	0.000987	99.9724

Table 2. Species caught in plastic traps, 1986-2003 (Con'td)

Species	#	%	Cum %
Prodotia iostomus	1	0.000987	99.9734
Murex pele	1	0.000987	99.9743
Bursa granularis	1	0.000987	99.9753
Strombus helli	1	0.000987	99.9763
Cerithium sp.	1	0.000987	99.9773
Pseudosquilla oculata	1	0.000987	99.9783
Pilumnus sp	1	0.000987	99.9793
Pilodius areolatus	1	0.000987	99.9803
Pilodius flavus	1	0.000987	99.9812
Neoliomera immigrans	1	0.000987	99.9822
Xanthias glabrous	1	0.000987	99.9832
Lophozozymus pulchellus	1	0.000987	99.9842
Lophozozymus intonsus	1	0.000987	99.9852
Percnon abbreviatum	1	0.000987	99.9862
Thalamita crenata	1	0.000987	99.9872
Thalamita coeruleipes	1	0.000987	99.9882
Thalamita kukenthali	1	0.000987	99.9891
Thalamita alcocki	1	0.000987	99.9901
Charybdis erythrodactyla	1	0.000987	99.9911
Portunus nipponensis	1	0.000987	99.9921
Osachila japonica	1	0.000987	99.9931
Lambrachaeus ramifer	1	0.000987	99.9941
Leucosiidae	1	0.000987	99.9951
Paromola japonica	1	0.000987	99.9961
Munida sp.	1	0.000987	99.9970
Saron marmoratus	1	0.000987	99.9980
Oplophorus gracilirostris	1	0.000987	99.9990
Amphipoda	1	0.000987	100.0000

Table 3. Mean catch rates of spiny and slipper lobster by gear type (number of lobsters per trap haul).

	Mean CPUE 1986-88	
	Wire	Plastic
Spiny	2.62	2.64
Slipper	0.20	1.19

Table 4. Significant changes in diversity and major species abundance through time.

	Necker 18-37			Necker 38-91			Maro 18-37			Maro 38-91		
	slope	r squared	p	slope	r squared	p	slope	r squared	p	slope	r squared	p
Diversity Indices												
Simpson's Index 1/D	0.18	0.67	0.0002	0.34	0.67	0.0002	-0.078	0.38	0.01	0.026	0.02	0.61
Simpson's Evenness $E_{1/D}$	-0.002	0.18	0.11	0.0003	0.00	0.87	-0.006	0.73	0.00002	-0.014	0.62	0.0005
Margalef's Index	0.44	0.91	0.00000005	0.43	0.74	0.00004	0.164	0.40	0.008	0.240	0.60	0.0006
Effort vs Margalef's Index	0.003	0.74	0.00004	0.007	0.90	0.00000008	0.004	0.48	0.003	0.021	0.75	0.00003
Abundance Indices												
Spiny Lobster	-0.10	0.60	0.0004	-0.14	0.61	0.0004	-1.188	0.51	0.001	-0.207	0.18	0.09
Slipper Lobster	-0.06	0.37	0.01	-0.07	0.19	0.09	0.081	0.78	0.000002	0.044	0.22	0.06
Hermit Crabs	0.06	0.43	0.006	0.02	0.03	0.51	0.022	0.04	0.44	0.039	0.03	0.52
Calappid Crabs	0.24	0.64	0.0002	0.14	0.60	0.0004	0.021	0.03	0.49	0.071	0.23	0.05
Portunid Crabs	0.08	0.37	0.01	-0.35	0.09	0.26	0.064	0.31	0.02	0.077	0.35	0.01
Heniochus	0.04	0.00	0.84	-0.28	0.08	0.30	0.937	0.08	0.26	0.438	0.07	0.31
Moray Eels	-0.04	0.21	0.08	-0.01	0.01	0.69	-0.023	0.13	0.16	-0.015	0.01	0.73
Whitetip Reef Shark	0.48	0.54	0.001	0.10	0.45	0.005	0.232	0.37	0.009	-0.108	0.16	0.11
	All Banks 10-20			All Banks 21-50								
Octopus	-0.0001	0.08	0.29	-0.0003	0.10	0.26						

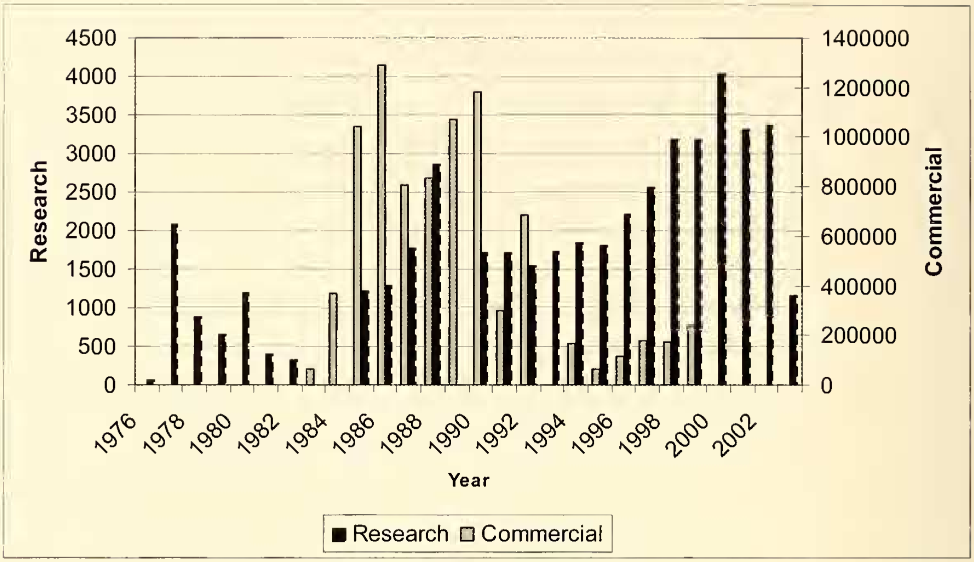

Figure 1. Commercial and research lobster trapping effort in trap hauls. (Commercial effort data is not available prior to the implementation of a Federal logbook system in mid-1983).

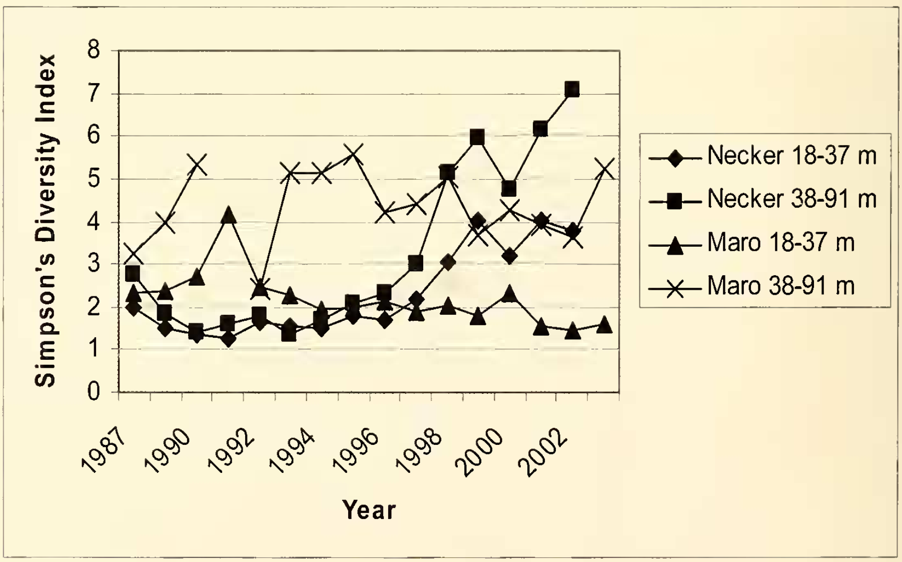

Figure 2. Diversity indices.

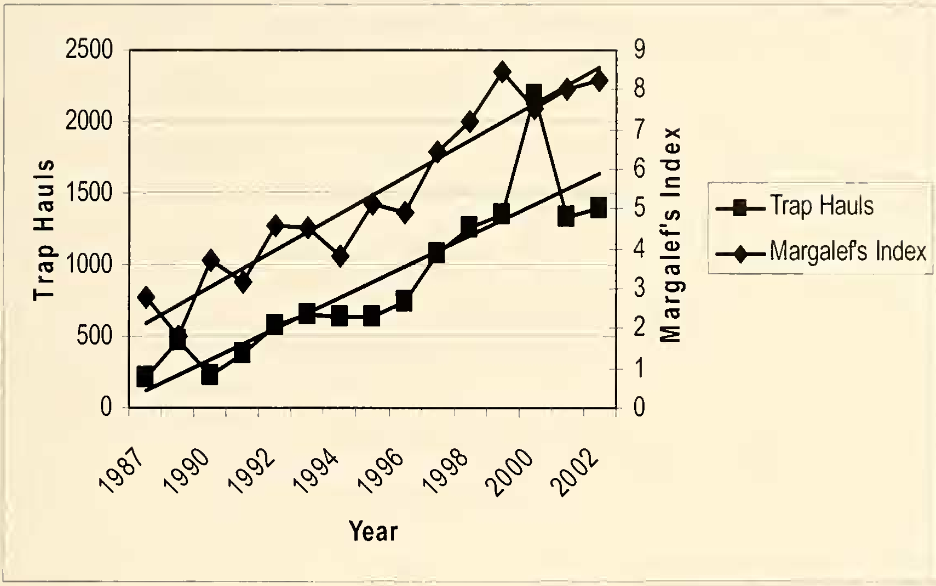

Figure 3. Species richness and trapping effort .

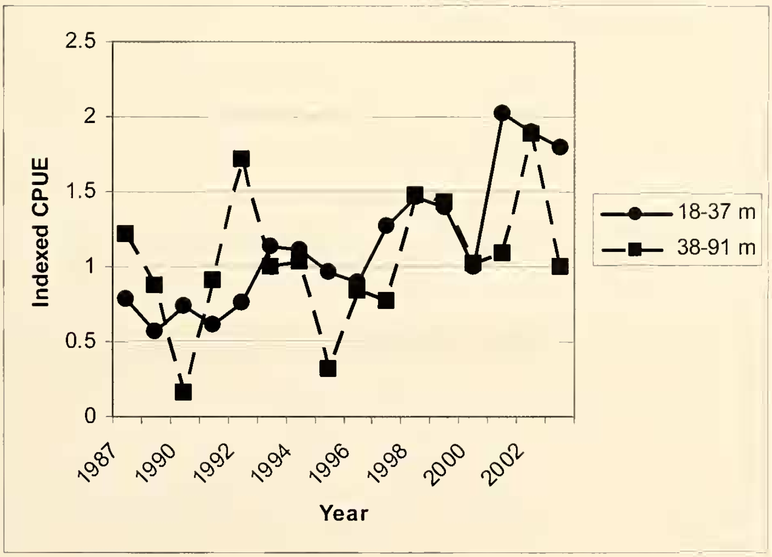

Figure 4. Indexed CPUE for slipper lobster at Maro Reef

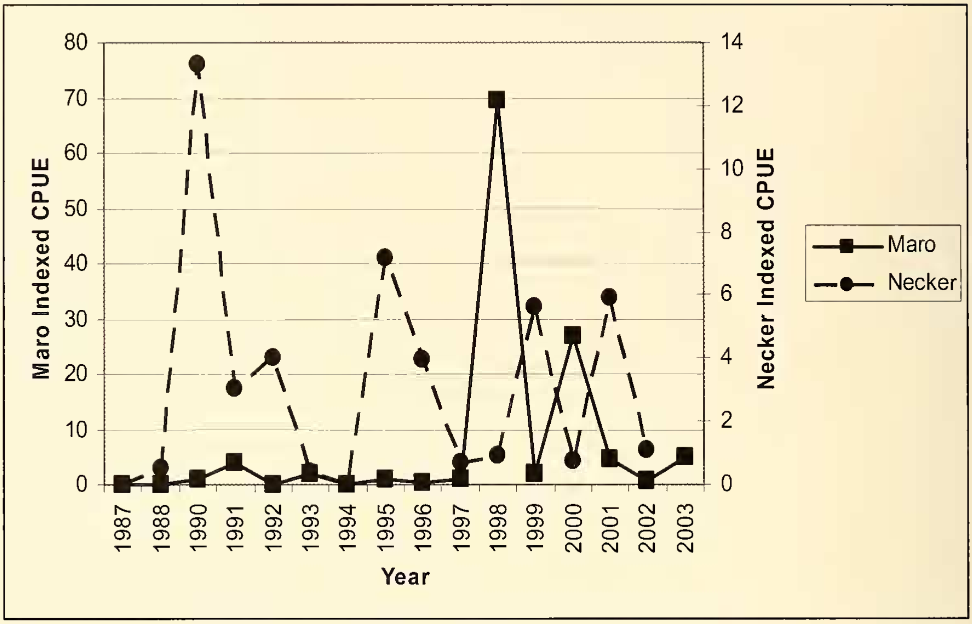

Figure 5. Indexed CPUE for *Heniochus diphreutes*.

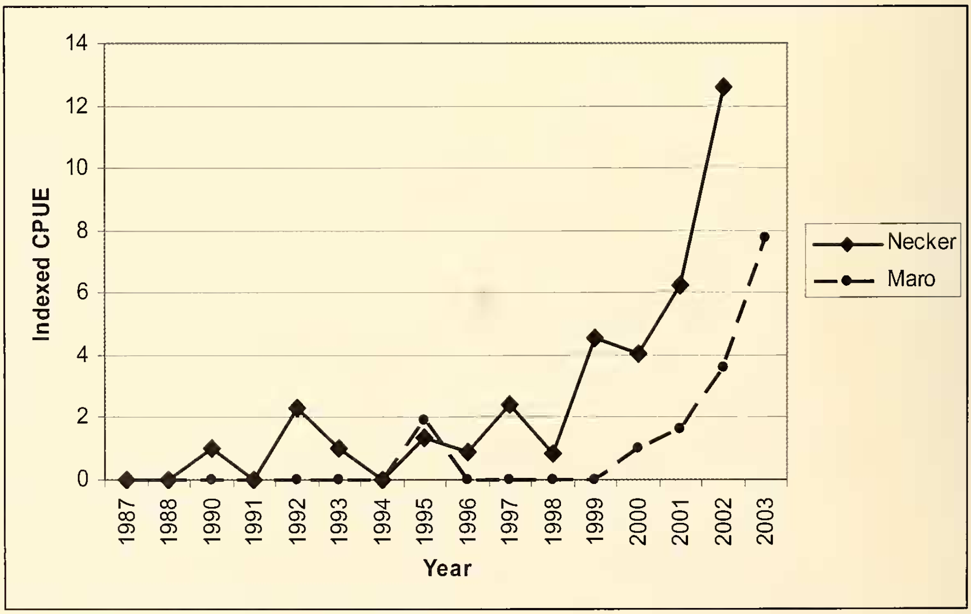

Figure 6. Indexed CPUE for whitetip reef shark.

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